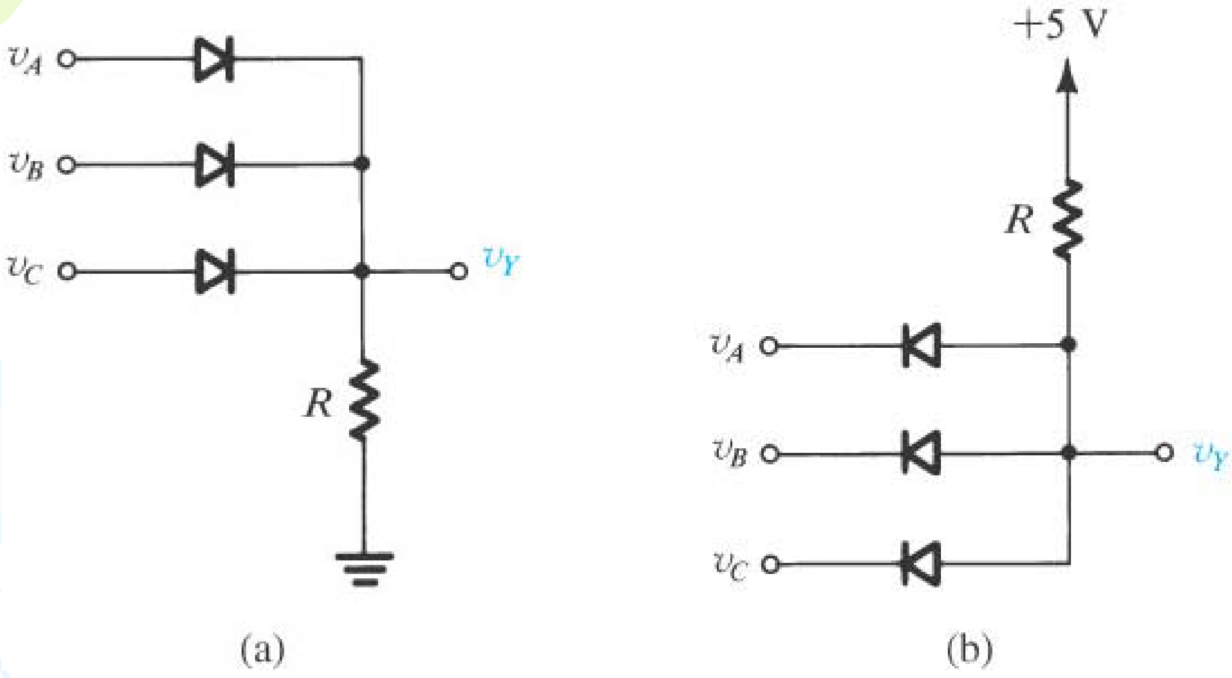
Lecture 03

Diode circuits

topics

- Rectifier circuit
- Limiting and clamping circuits
- Small signal model

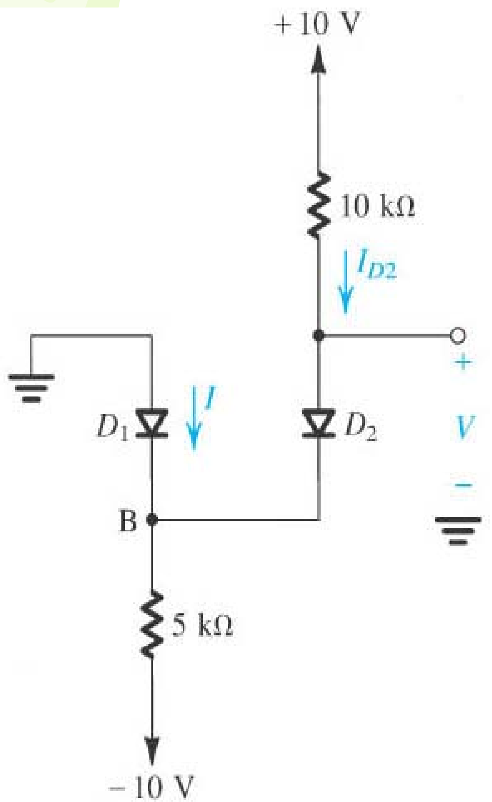
Diode logic gates (ideal diode)



$$Y = A + B + C$$

$$Y = ABC$$

Example (ideal diode)



(a)

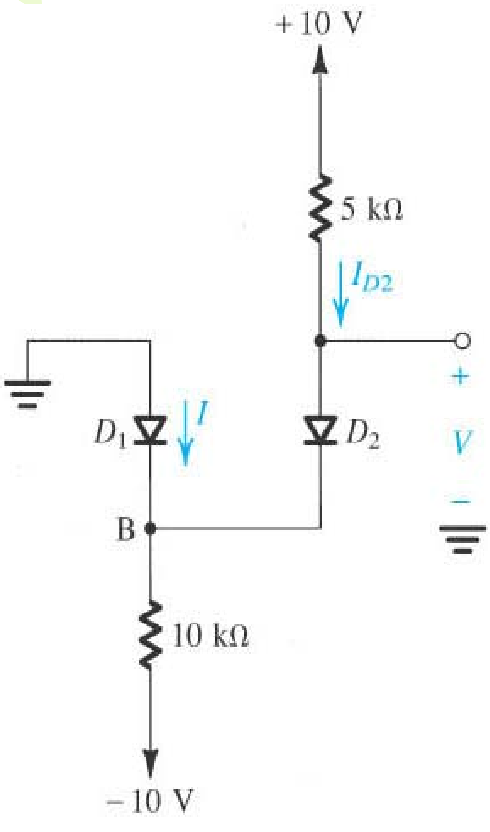
Assume D1 and D2 are ideal diodes and conducting

$$I_{D2} = \frac{10-0}{10k} = 1mA$$

$$0 = 5k \times (I + I_{D2}) - 10v$$

$$\Rightarrow I = 1mA$$

Example (ideal diode)



(b)

Assuming that D1 and D2 are ideal diodes and conducting

$$I_{D2} = \frac{10-0}{5k} = 2mA$$

$$0 = 10k \times (I + I_{D2}) - 10v$$

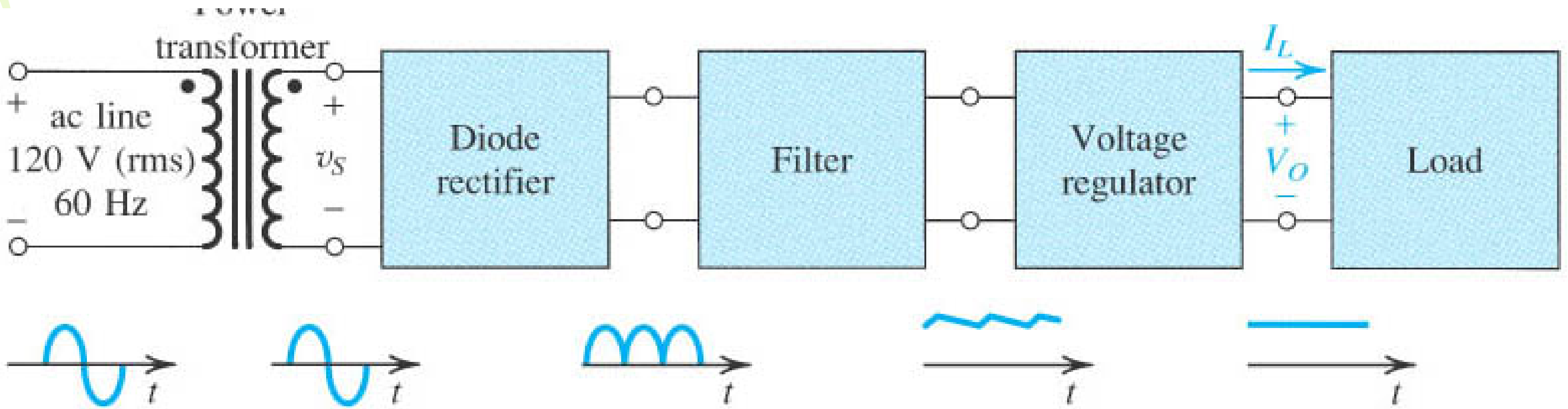
$$\Rightarrow I = -1mA$$ Contradictory result

Assuming that D1 is off and D2 is on

$$I_{D2} = \frac{10-(-10)}{15k} = 1.33mA$$

$$V_B = 10k \times I_{D2} - 10v = 3.3v$$

AC→DC Rectifier



Rectifier parameters:

- Crest factor (C.F.)
- Form factor (F.F.)
- Ripple factor (R.F.)

$$C.F. = \frac{V_{\max}}{V_{rms}}$$

$$F.F. = \frac{V_{rms}}{V_{average}}$$

$$R.F. = \frac{V_{ripple-rms}}{V_{average}}$$

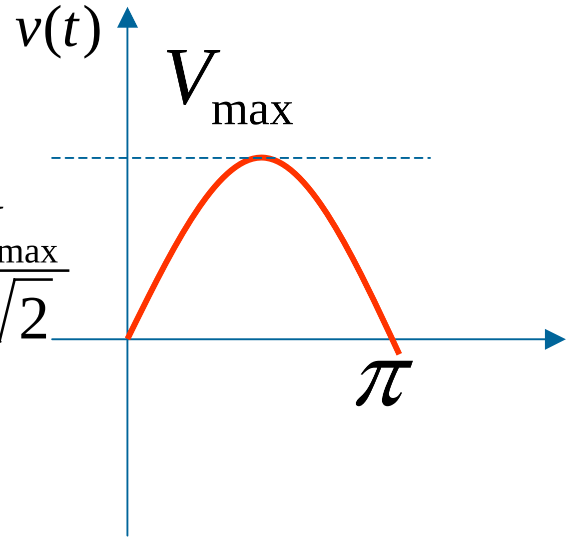
$$V_{average} = \frac{1}{T}\int_0^T V_o(t)\,dt$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V_o^2(t)\,dt}$$

Root-mean-square

$$V_{average} = \frac{1}{T}\int_0^T v(t)dt = \frac{1}{\pi}\int_0^\pi V_{max}\sin\theta d\theta = \frac{2V_{max}}{\pi}$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} = \sqrt{\frac{1}{\pi}\int_0^\pi V^2{}_{max}\sin^2\theta d\theta} = \frac{V_{max}}{\sqrt{2}}$$



$$\int_0^\pi \sin\theta d\theta = -\cos\theta\Big|_0^\pi = 2$$

$$\int_0^\pi \sin^2\theta d\theta = \int_0^\pi \frac{1-\cos 2\theta}{2}d\theta = \frac{\pi}{2}$$

Full-wave rectifier

$$V_{average} = \frac{2V_{max}}{\pi}$$

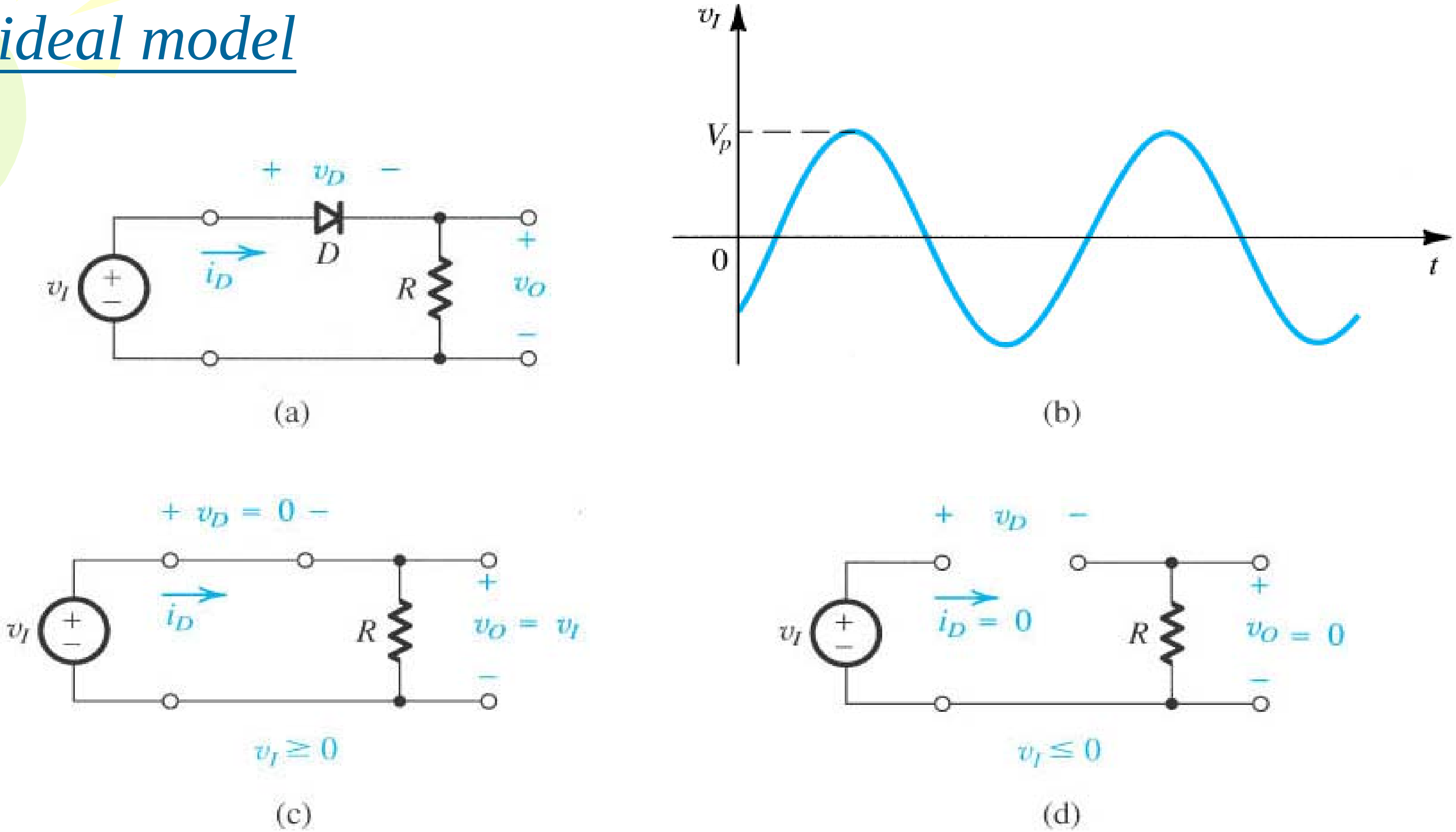
$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

Half-wave rectifier

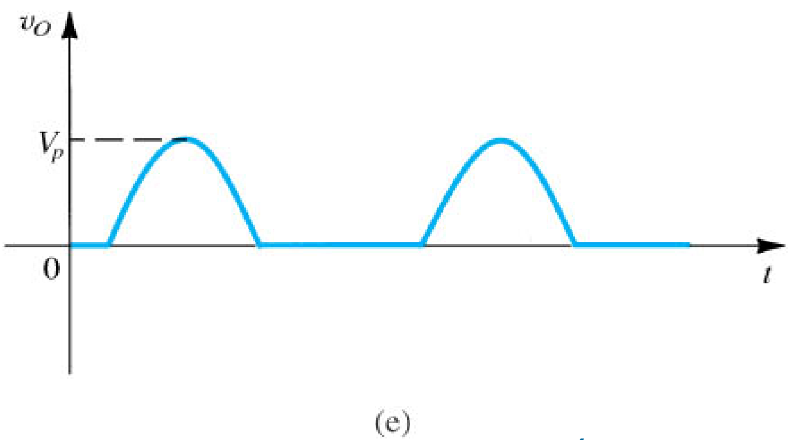
$$V_{average} = \frac{V_{max}}{\pi}$$

$$V_{rms} = \frac{V_{max}}{2}$$

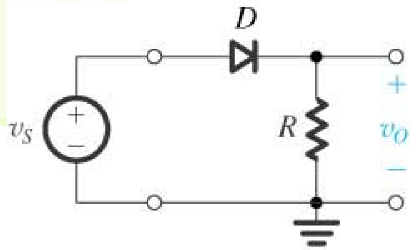
Using ideal model



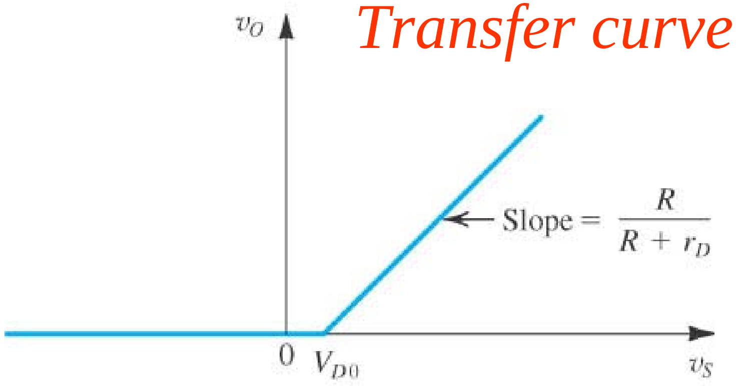
Half-wave rectifier



Using piecewise-linear model

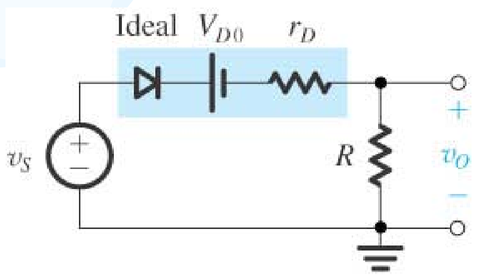


(a)

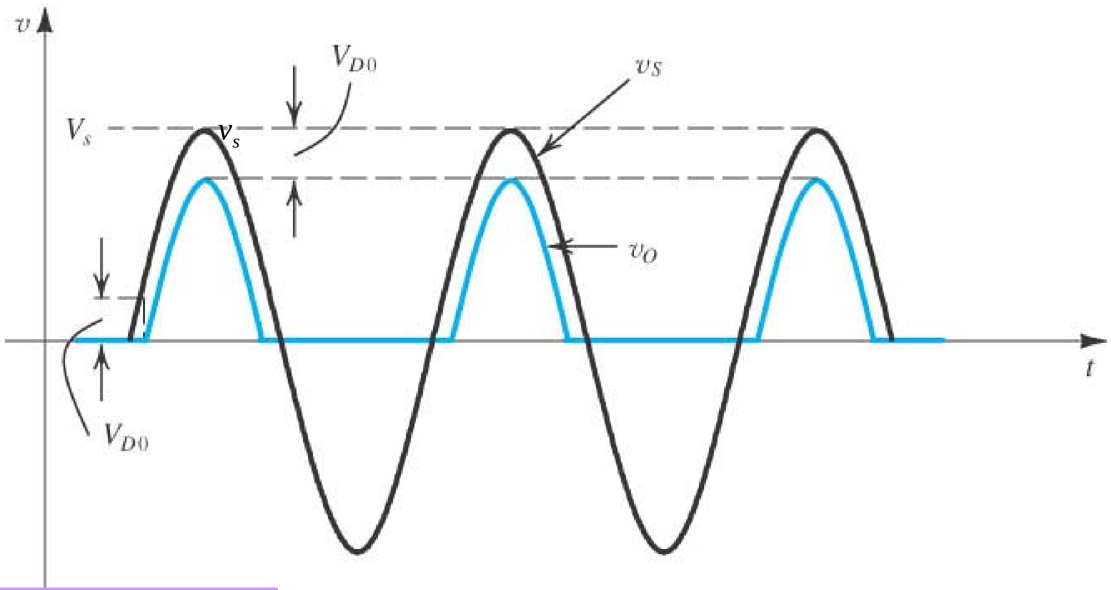


(c)

$$v_o = \frac{R}{R + r_D} v_s - \frac{R}{R + r_D} V_{D0}$$



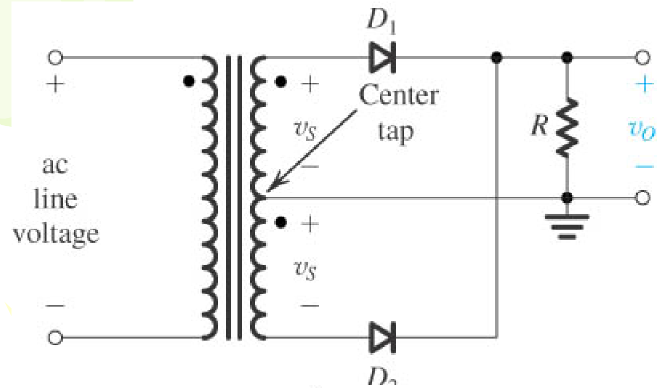
(b)



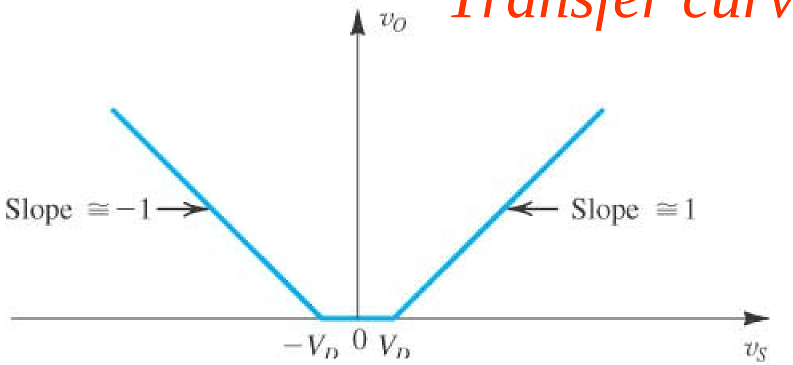
(d)

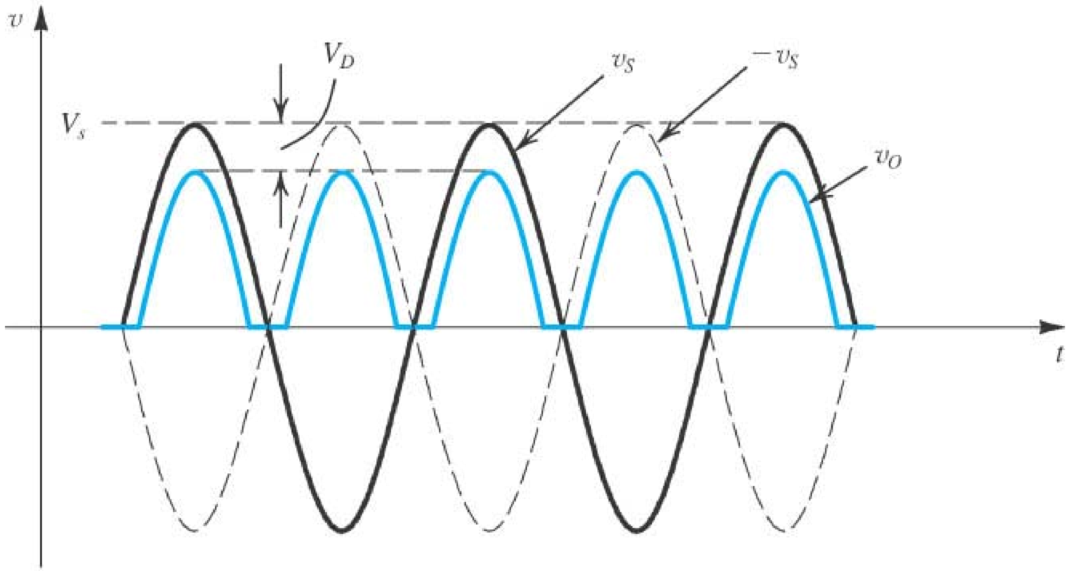
PIV (peak inverse voltage) = v_s

Using piecewise-linear model (center-tapped Rectifier)



Transfer curve

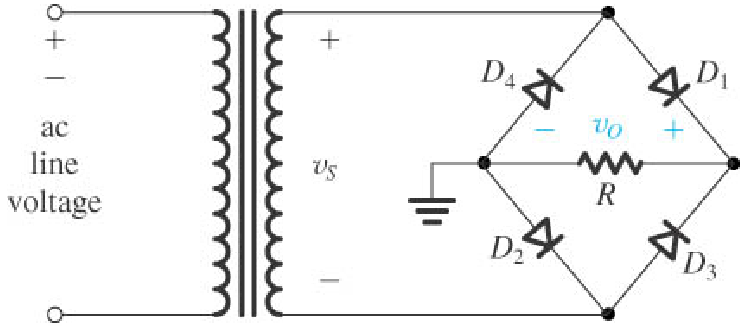




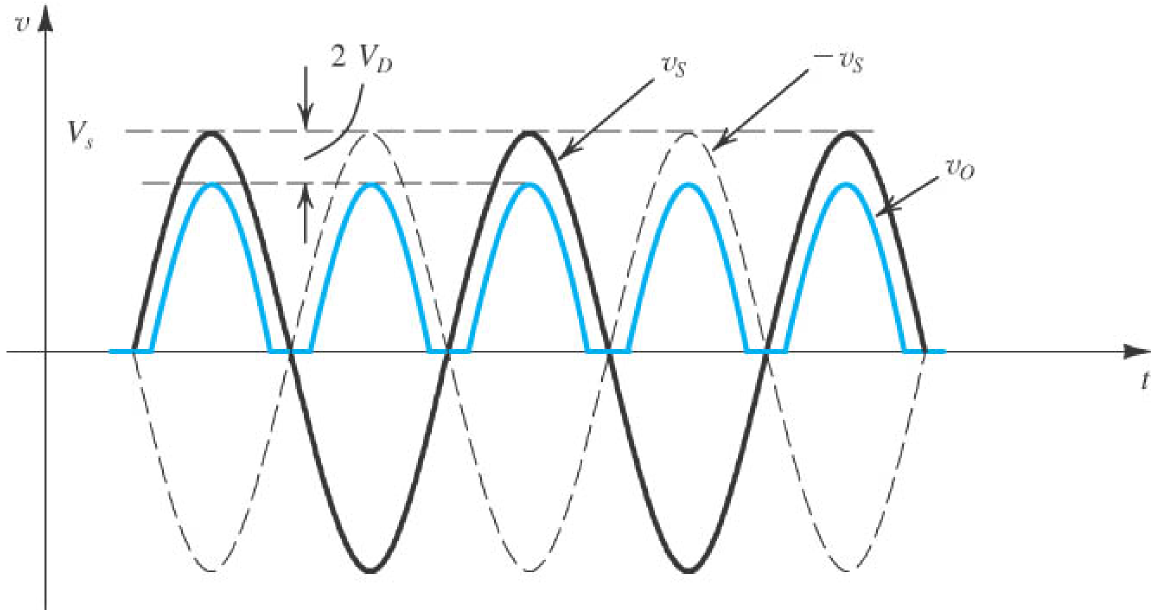
(c)

PIV (peak inverse voltage) = $2v_s - V_D$

Bridge rectifier



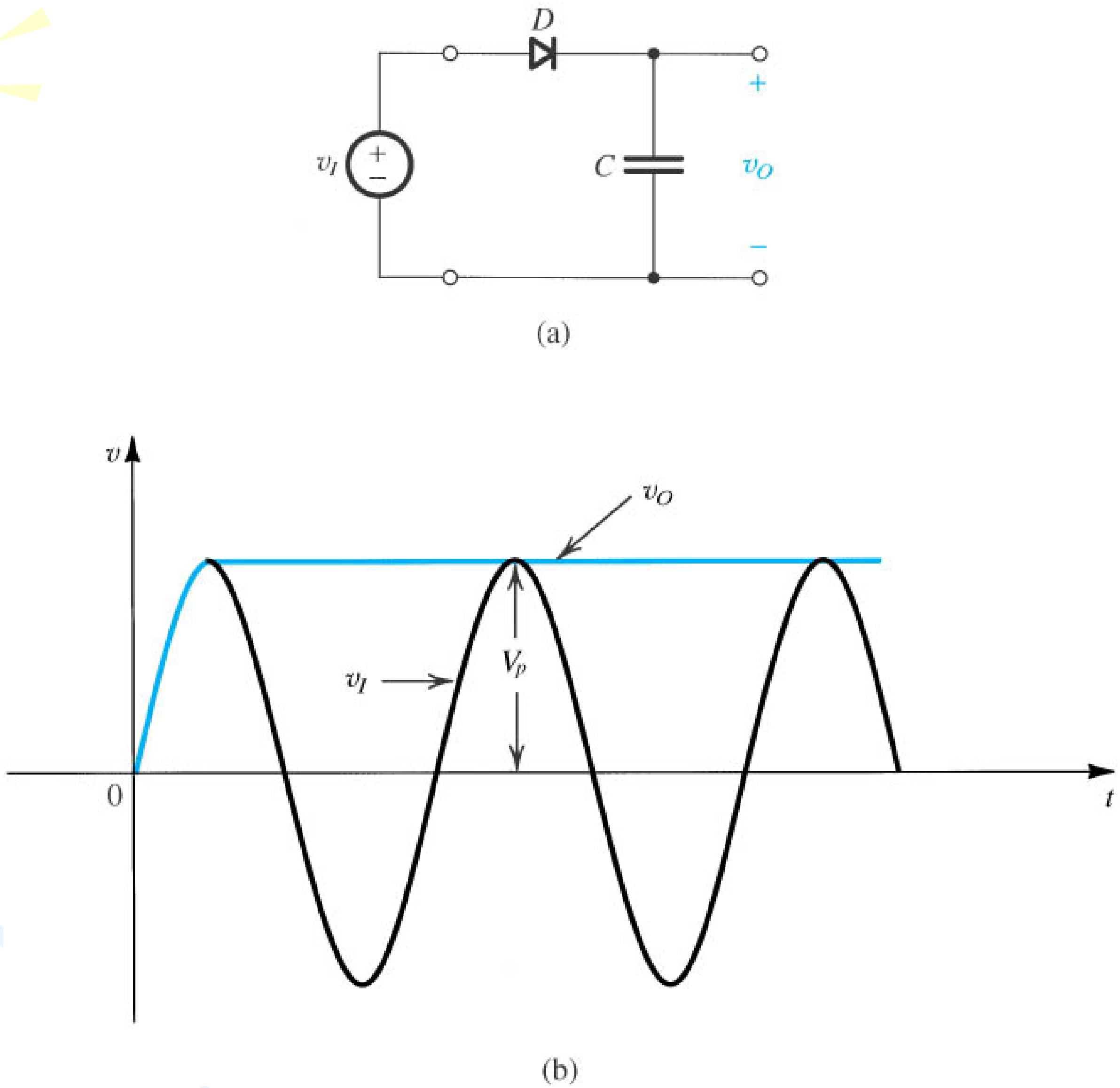
(a)

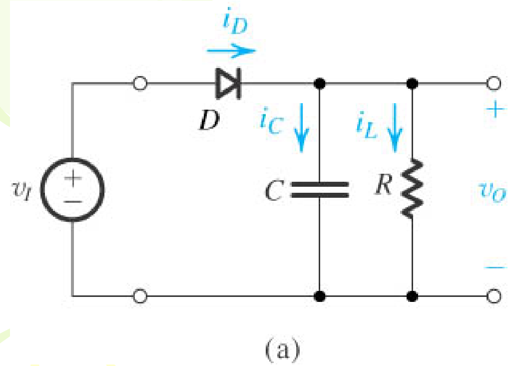


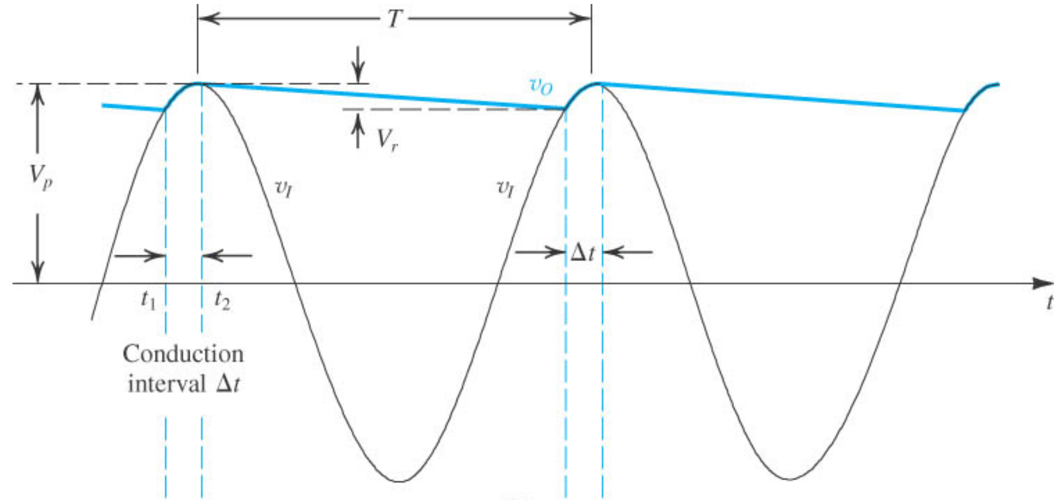
PIV (peak inverse voltage) = $v_s - 2V_D + V_D = v_s - V_D$

	Half-wave	Center-tapped	bridge
v_i	$v_{\max}\sin\omega t$	$v_{\max}\sin\omega t$	$v_{\max}\sin\omega t$
v_0	$V_{\max}-V_D$	$V_{\max}-V_D$	$V_{\max}-2V_D$
$V_{average}$	$\frac{V_{\max}-V_D}{\pi}$	$\frac{2(V_{\max}-V_D)}{\pi}$	$\frac{2(V_{\max}-V_D)}{\pi}$
V_{rms}	$\frac{V_{\max}-V_D}{2}$	$\frac{V_{\max}-V_D}{\sqrt{2}}$	$\frac{V_{\max}-V_D}{\sqrt{2}}$
PIV	$V_{\max}$	$2V_{\max}-V_D$	$V_{\max}-V_D$
$F.F.$	$\frac{\pi}{2}$	$\frac{\pi}{2\sqrt{2}}$	$\frac{\pi}{2\sqrt{2}}$
$R.F.$	$\sqrt{(\frac{\pi}{2})^2-1}$	$\sqrt{(\frac{\pi}{2\sqrt{2}})^2-1}$	$\sqrt{(\frac{\pi}{2\sqrt{2}})^2-1}$

Filter







$$i_D = i_C + i_L = C\frac{dv_I}{dt} + \frac{v_o}{R}$$

$$C\frac{dv_o}{dt} + \frac{v_o}{R} = 0$$

$$\frac{dv_o(t)}{dt} = -\frac{v_o(t)}{RC}, \quad v_o(0) = V_p$$

$$v_o(t) = ke^{-\frac{t}{RC}}, \quad k = V_p$$

$$v_o(t) = V_p e^{-\frac{t}{RC}}$$

$$RC >> T$$

$$V_p - V_r = V_p e^{-\frac{T}{RC}}$$

$$e^{-\frac{T}{RC}} \approx 1 - \frac{T}{RC}$$

$$V_r \approx V_p \frac{T}{RC} = \frac{V_p}{fRC}$$

Half wave

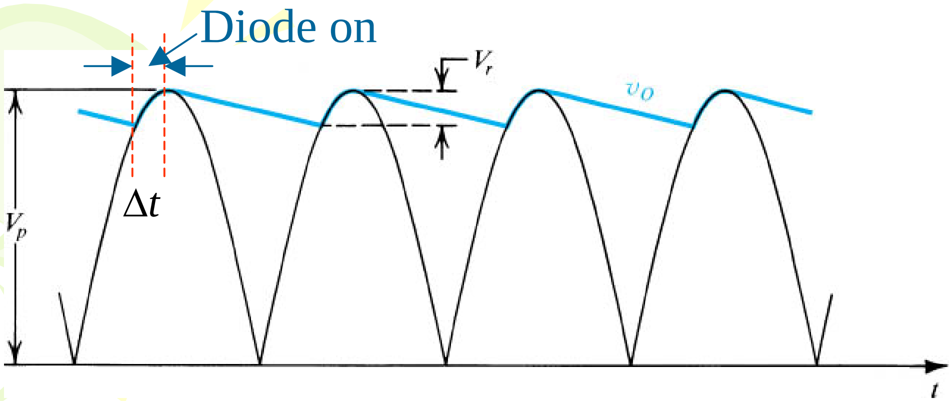
Average diode current i_{Dav}

$$\boxed{i_{Dav} = I_L(1 + \pi\sqrt{2V_p / V_r})}$$

Average diode current $i_{D\max}$

$$\boxed{i_{D\max} = I_L(1 + 2\pi\sqrt{2V_p / V_r})}$$

next page



$$V_p - V_r = V_p e^{-\frac{T}{2RC}}$$

$$e^{-\frac{T}{2RC}} \approx 1 - \frac{T}{2RC}$$

full wave

$$V_r \approx V_p \frac{T}{RC} = \frac{V_p}{2fRC}$$

Average diode current i_{Dav}

$$V_p \cos(\omega \Delta t) = V_p - V_r$$

$$\Rightarrow V_p[1 - \frac{1}{2}(\omega \Delta t)^2] = V_p - V_r$$

$$\frac{V_p}{2}(\omega \Delta t)^2 = V_r \Rightarrow \omega \Delta t = \sqrt{\frac{2V_r}{V_p}}$$

$$Q_c = i_c \Delta t = (i_{Dav} - I_L)\Delta t$$

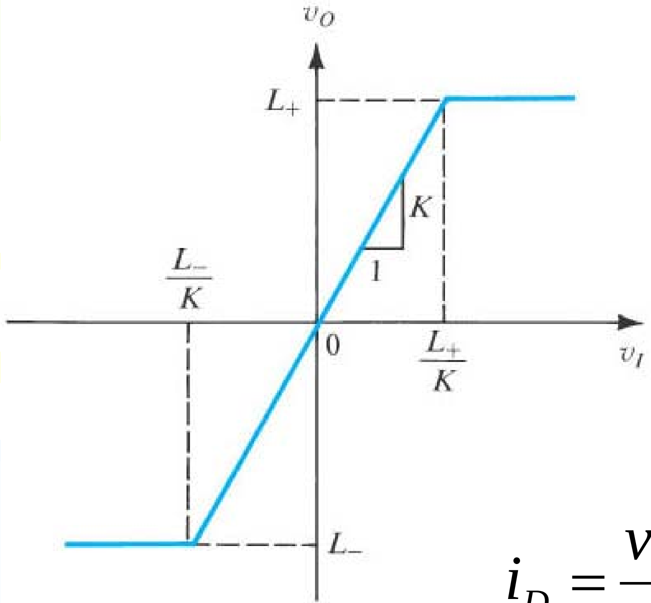
$$\Rightarrow i_{Dav} = I_L + \frac{Q_c}{\Delta t} = I_L + \frac{CV_r}{\Delta t}$$

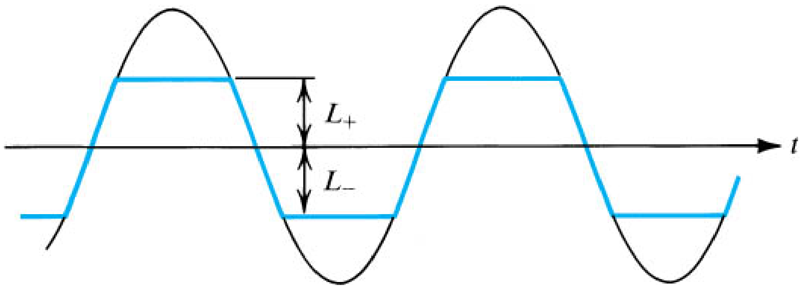
$$\boxed{i_{Dav} = \frac{V_p}{R}(1 + \pi \sqrt{V_p / 2V_r})}$$

Maximum diode current $i_{D\max}$

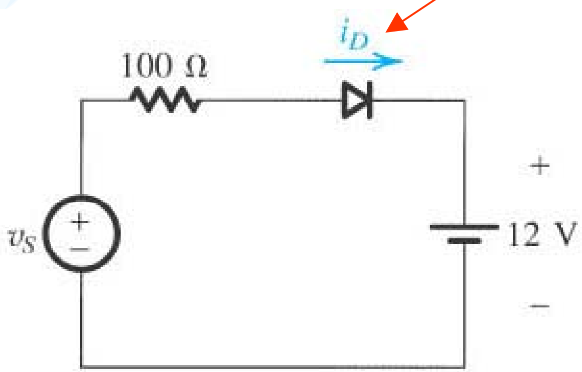
$$i_{D\max} = \frac{V_p}{R}(1 + 2\pi \sqrt{V_p / 2V_r})$$

Limiter circuits

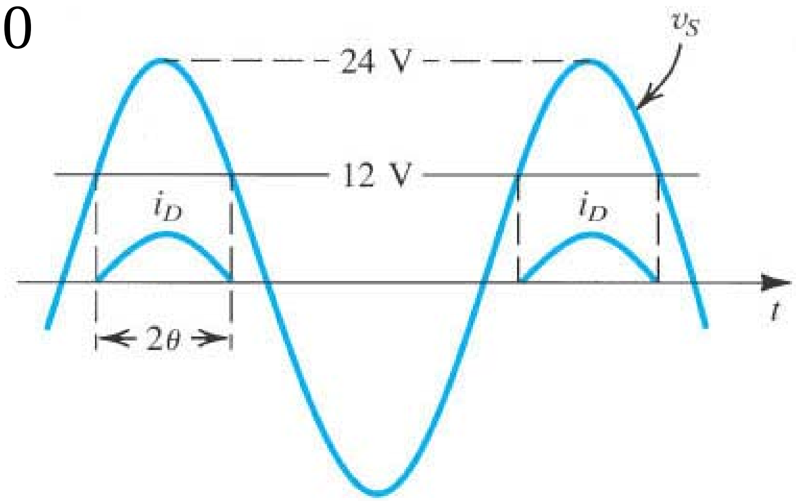




$$i_D = \frac{v_s - 12}{100}$$

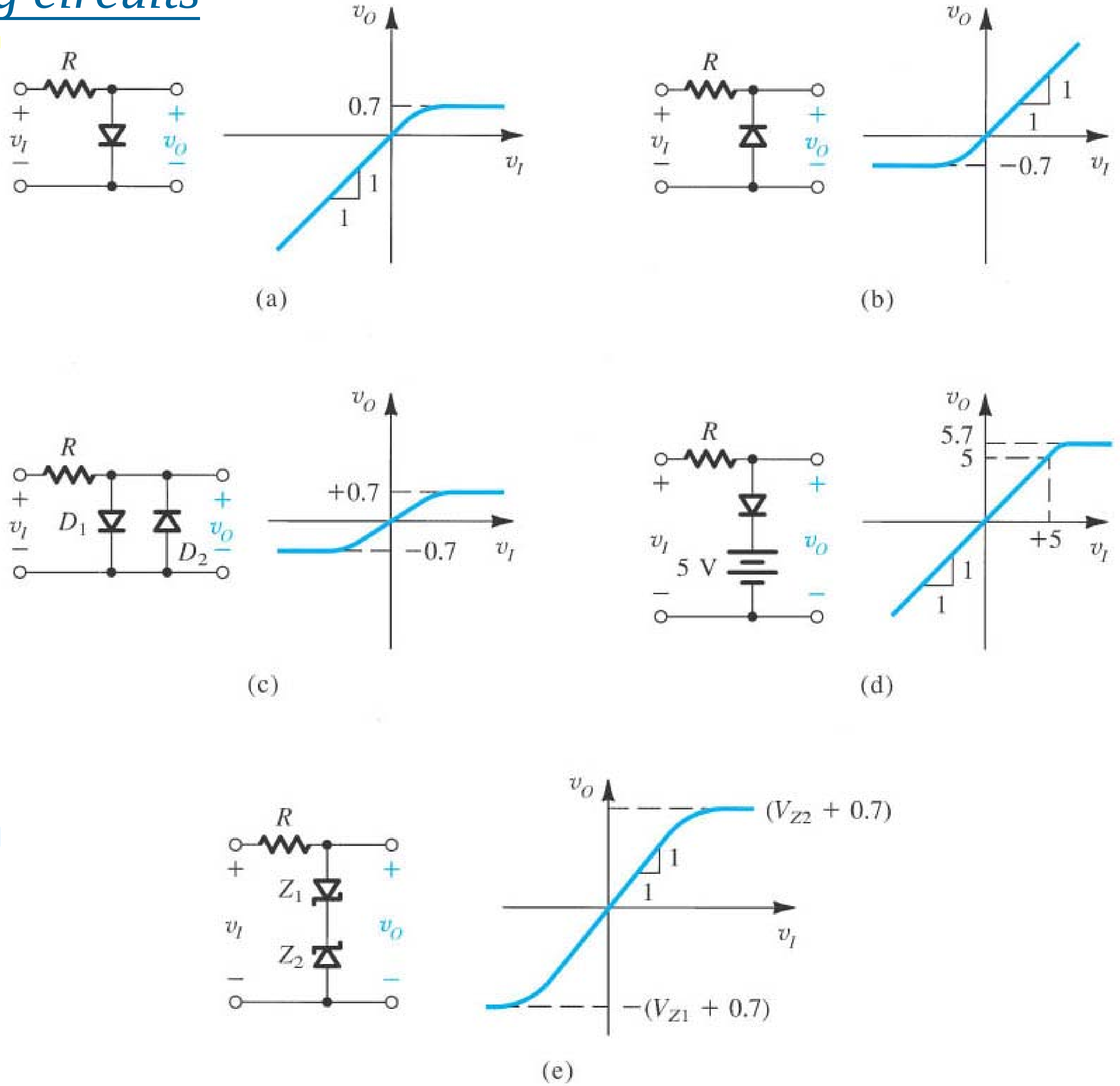


(a)

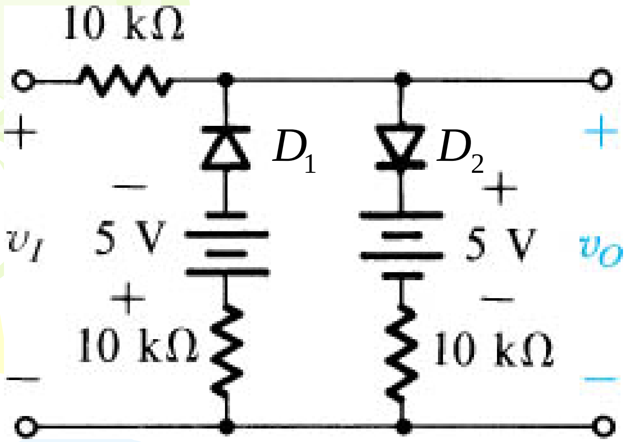


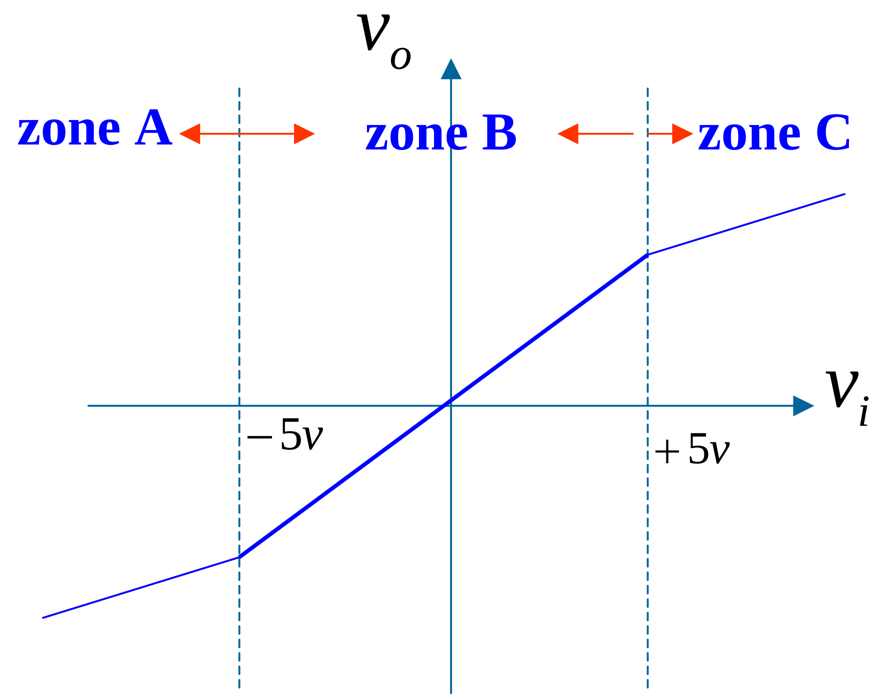
(b)

Basic limiting circuits



[example](#)





zone A : D_2 off, D_1 on

$$v_o = \frac{10k}{10k+10k} v_i + \frac{10k}{10k+10k}(-5v)$$

$$v_o = \frac{1}{2} v_i - 2.5v$$

zone B : D_2 off, D_1 off

$$v_o = v_i$$

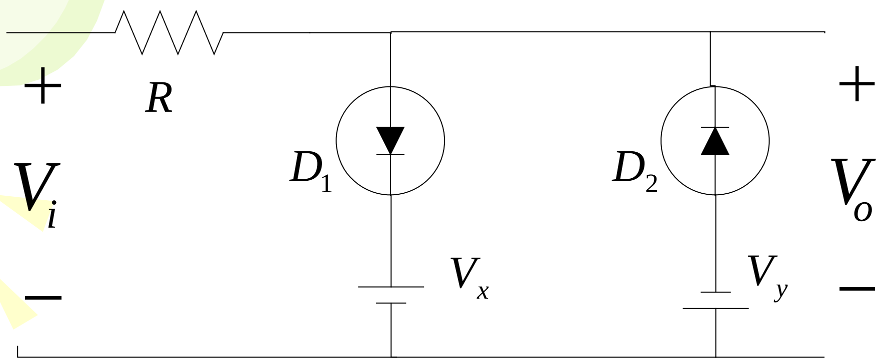
zone C : D_2 on, D_1 off

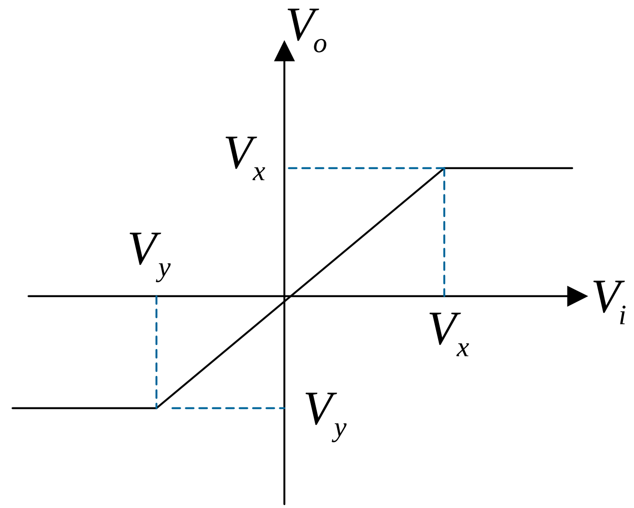
$$v_o = \frac{10k}{10k+10k} v_i + \frac{10k}{10k+10k}(5v)$$

$$v_o = \frac{1}{2} v_i + 2.5v$$

example

Ideal diodes





zone A : D_1 off, D_2 on

$$V_i < V_y \Rightarrow V_o = V_y$$

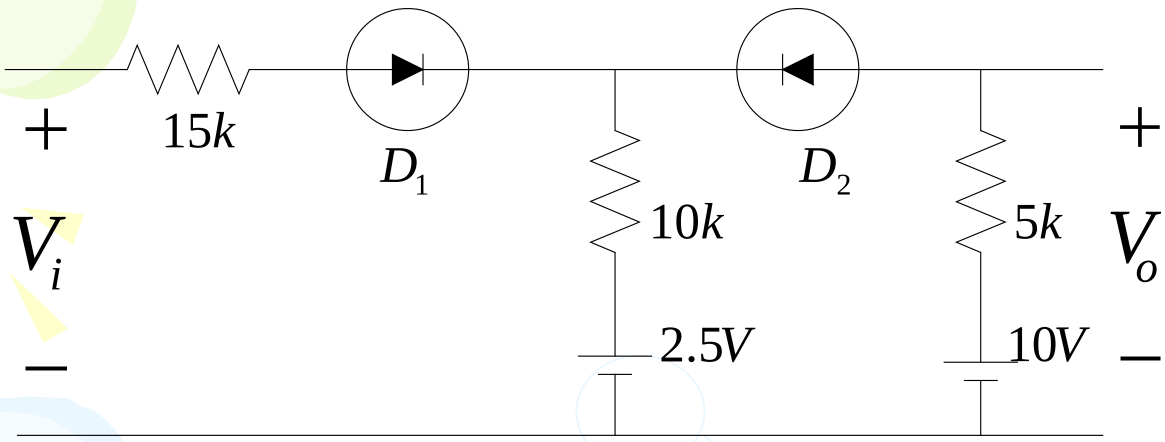
zone C : D_1 on, D_2 off

$$V_i > V_x \Rightarrow V_o = V_x$$

zone B : D_2 off, D_1 off

$$V_x > V_i > V_y \Rightarrow V_o = V_i$$

example



$$\boxed{V_i >> V_A}$$

$$D_1 on, D_2 off$$

$$\Rightarrow V_o = 10V$$

$$\boxed{V_i << V_B}$$

$$D_1 off, D_2 on$$

$$\Rightarrow V_o = 7.5V$$

$$\boxed{V_A > V_i > V_B \Rightarrow D_1 on, D_2 on}$$

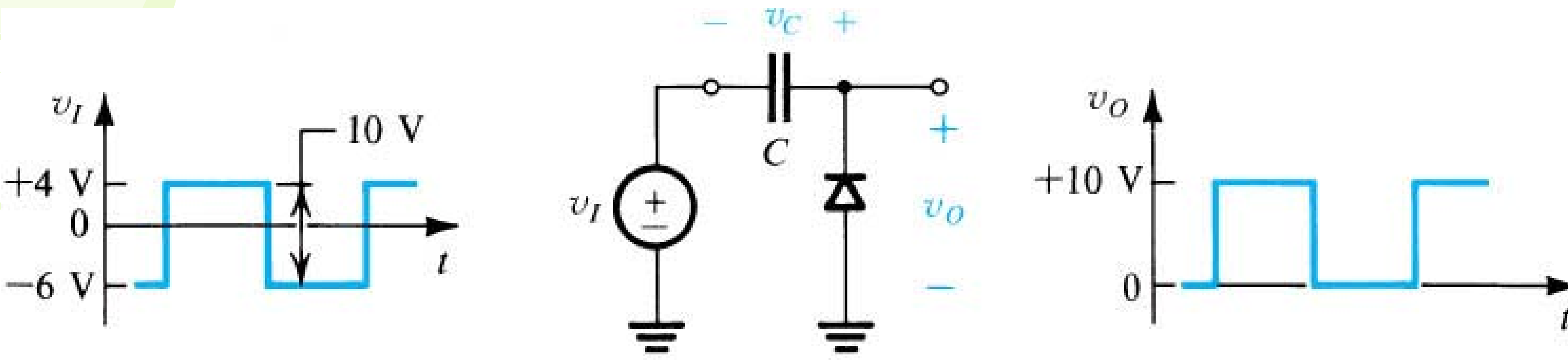
$$V_o = V_i \frac{(10//5)}{15+(10//5)} + 2.5\frac{(15//5)}{10+(15//5)} + 10\frac{(10//15)}{5+(10//15)}$$

$$= \frac{1}{11}(2V_i + 67.5)$$

$$V_o = 7.5V = \frac{1}{11}(2V_B + 67.5)$$

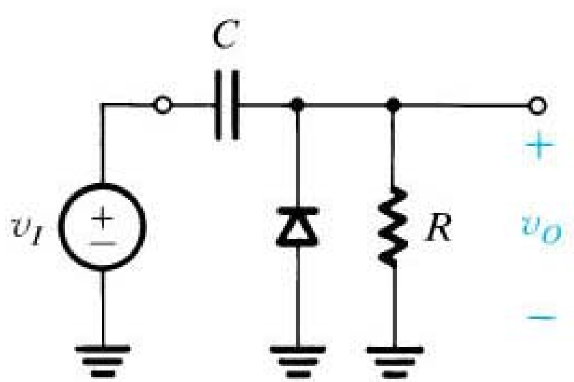
$$V_o = 10V = \frac{1}{11}(2V_A + 67.5)$$

DC restoration (clamping circuit)

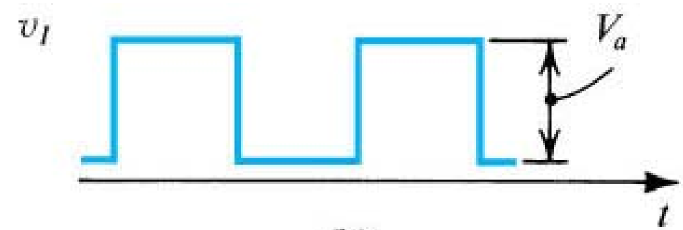


(a) (b) (c)

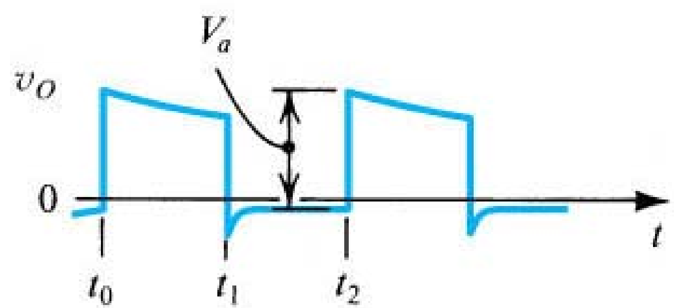
DC restoration with load



(a)

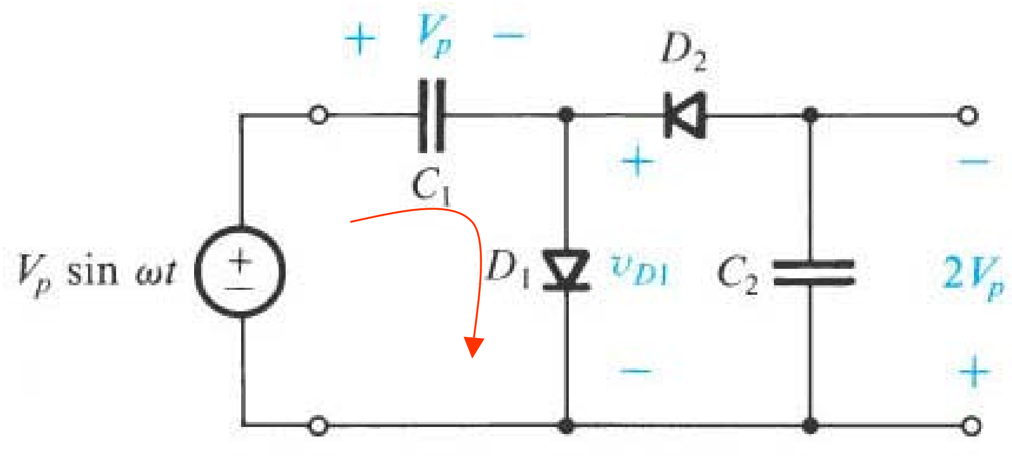


(b)

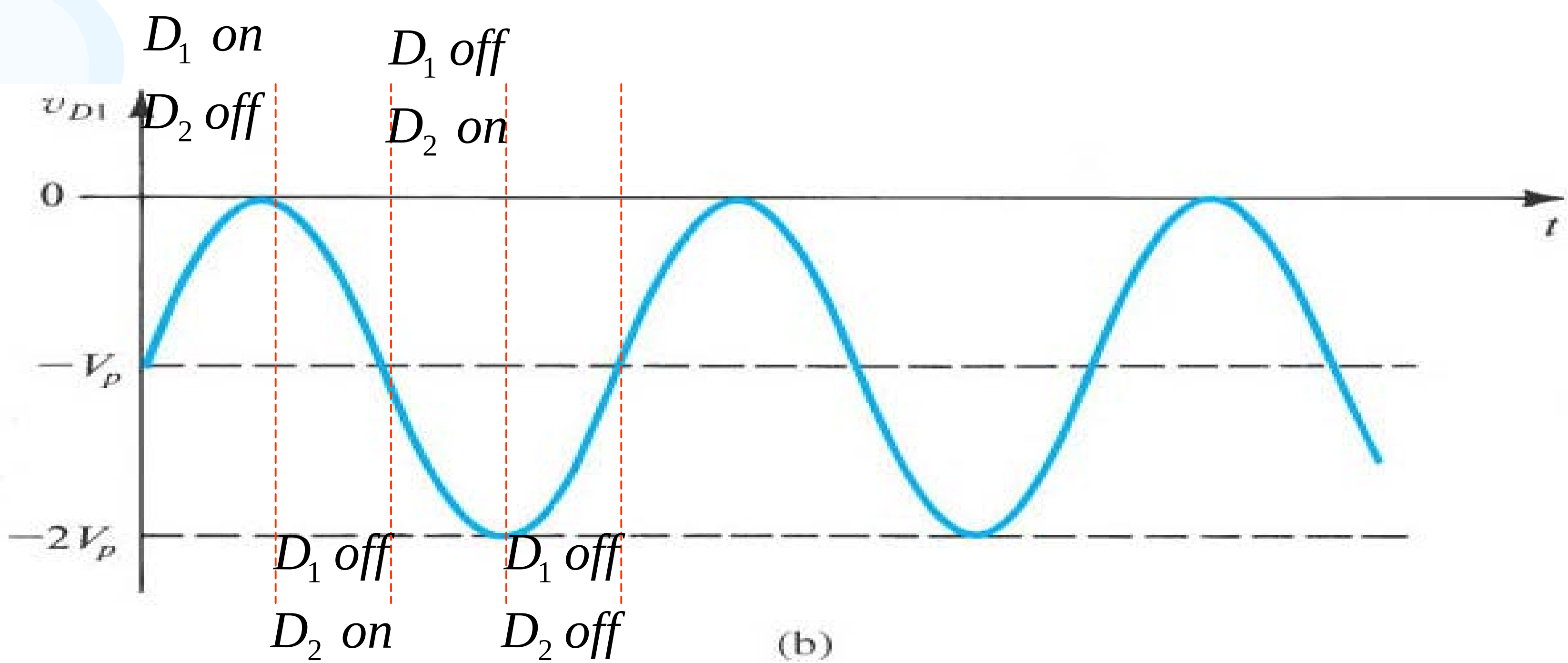


(c)

Voltage doubler

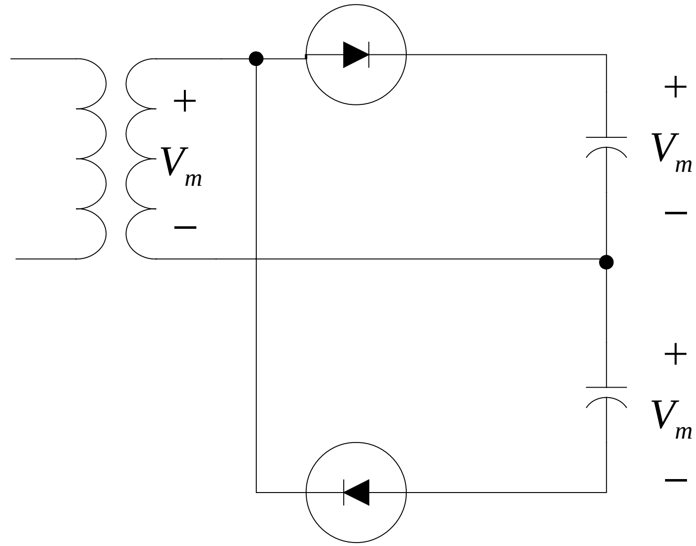


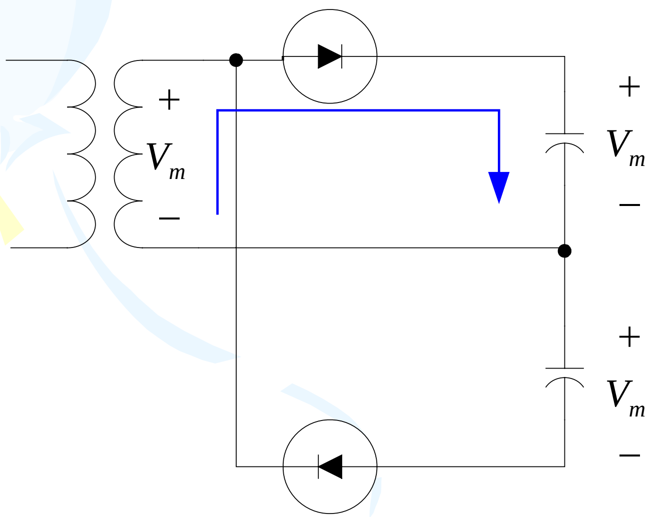
(a)

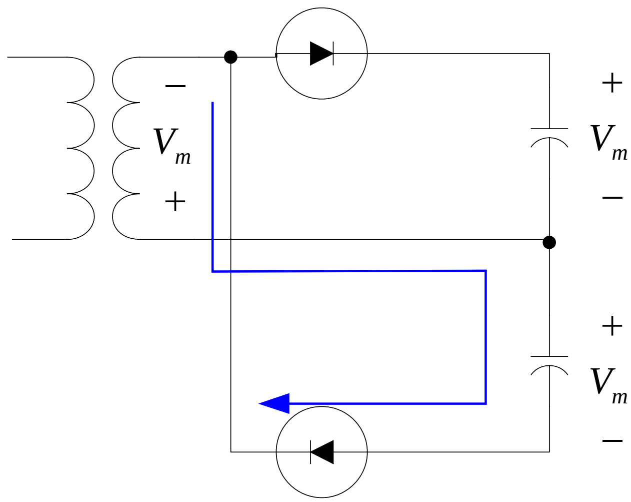


(b)

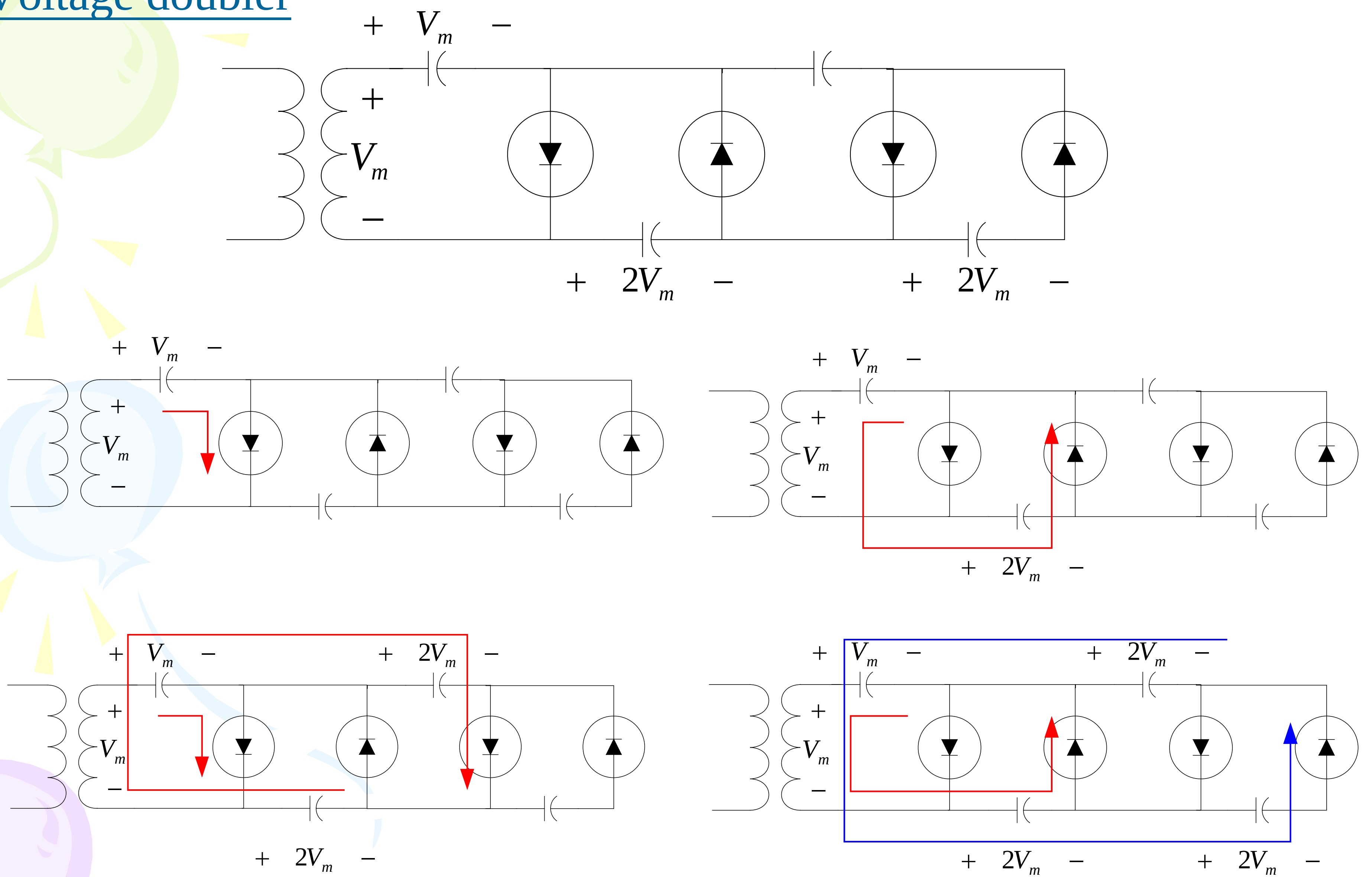
Voltage doubler



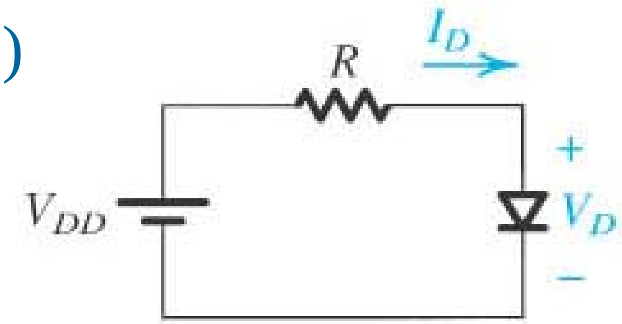


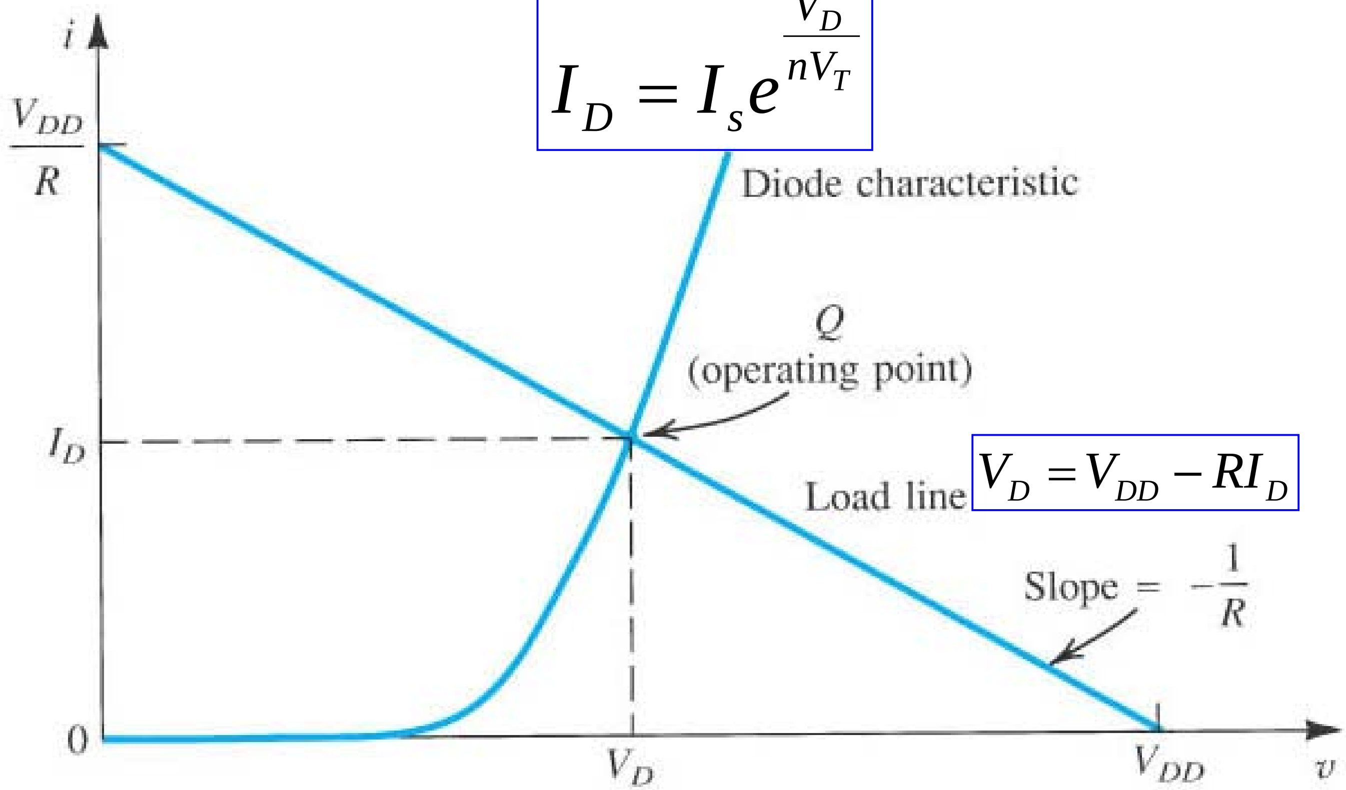


Voltage doubler



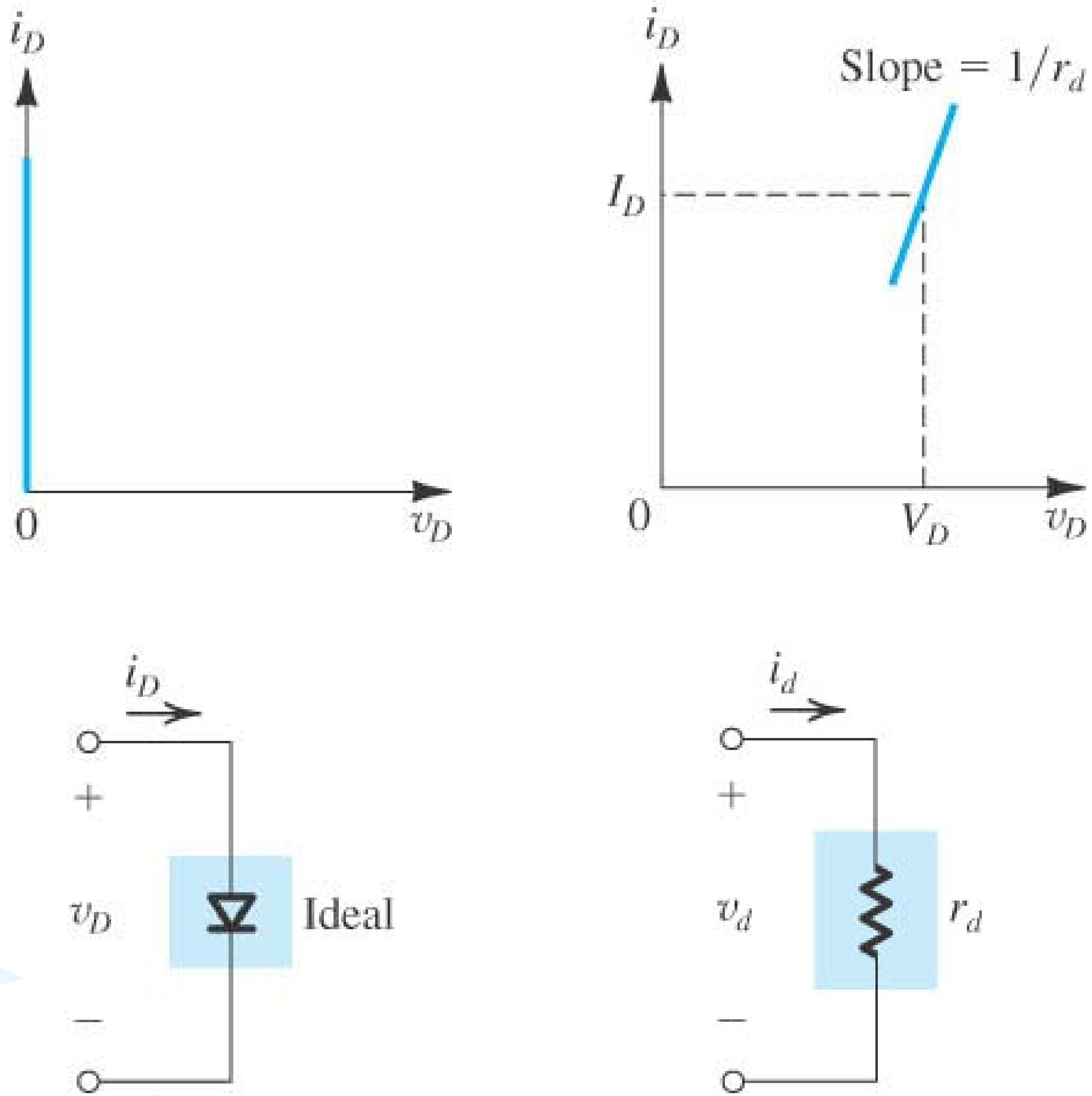
Operating point (DC analysis)



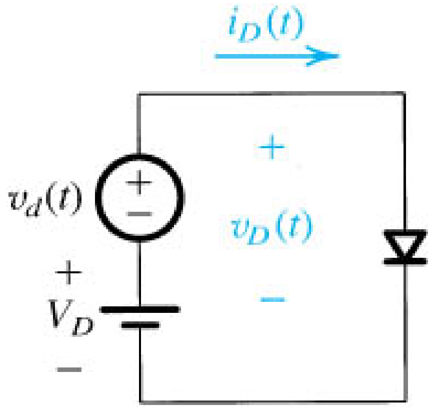


$$\boxed{I_D = I_s e^{\frac{V_D}{nV_T}}}$$

$$\boxed{V_D = V_{DD} - RI_D}$$


i_D
0
v_D
i_D
Slope = $1/r_d$
I_D
0
V_D
v_D
i_D
+
v_D
Ideal
−
i_d
+
v_d
r_d
−

small signal analysis (AC analysis)



(a)

$$I_D = I_s e^{\frac{V_D}{nV_T}}$$

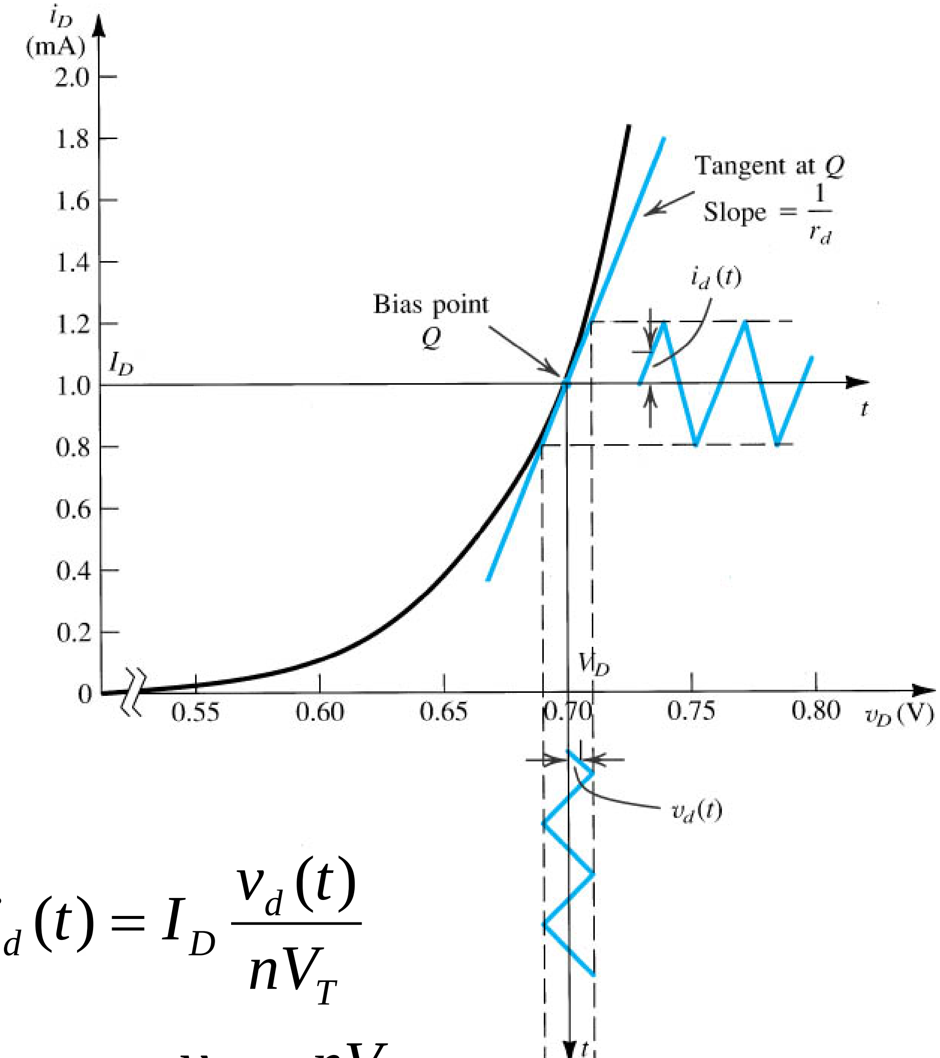
$$v_D = V_D + v_d(t)$$

$$i_D = I_s e^{\frac{v_D}{nV_T}} = I_s e^{\frac{(V_D + v_d(t))}{nV_T}} = I_s e^{\frac{V_D}{nV_T}} e^{\frac{v_d(t)}{nV_T}}$$

$$i_D = I_D e^{\frac{v_d(t)}{nV_T}}$$

$$\boxed{\frac{v_d(t)}{nV_T} << 1}$$ *small signal*

$$i_D \approx I_D \left(1 + \frac{v_d(t)}{nV_T}\right)$$

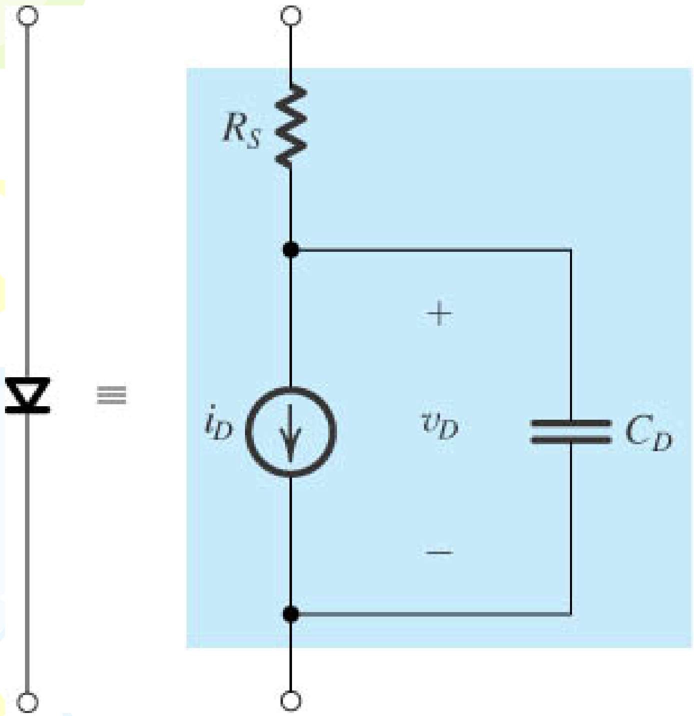


$$i_d(t) = I_D \frac{v_d(t)}{nV_T}$$

$$\Rightarrow r_d = \frac{v_d}{i_d} = \frac{nV_T}{I_D}$$

(b)

Diode Model (small signal model)



$$i_D = I_S\left(e^{v_D/nV_T} - 1\right)$$

$$C_D = C_d + C_j = \frac{\tau_T}{V_T} I_S\, e^{v_D/nV_T} + C_{j0} \Big/ \left(1 - \frac{v_D}{V_0}\right)^m$$